Multispecies workshop: Multispecies Models in the eastern Bering Sea

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Scientific Framework to provide ecosystem-based advice in the Bering Sea

- Main goals for protecting ecosystem attributes:
1. Maintain predator/prey relationships
2. Maintain energy flow and balance
3. Maintain diversity
- Tools:
1. Multispecies models (biological interactions)
2. Multispecies models (technological interactions) Full ecosystem models (ECOPATH, ECOSIM…)

Multispecies models (biological interactions)

- Deterministic models:
1. Multispecies virtual population analysis (MSVPA)
2. Multispecies forecasting model (MSFOR)
- Statistical models:
1. Multispecies statistical model (MSM)

Multispecies models (biological interactions)

- Deterministic models:
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Multispecies Virtual Population Analysis

- Developed by the multispecies working group from ICES
- Based on previous work of Gulland (1965), Andersen and Ursin (1977), Pope (1979) and Helgason and Gislason (1979)
- Incorporates the stomach content data in the estimation of the virtual population.

Multispecies virtual population analysis

- MSVPA is a recursive algorithm that calculates fishing mortality *F*, recruitment, stock size, **suitability coefficients** and **predation mortality** based mainly on catch-at-age data, predator ration and predator diet information.

MSVPA characteristics

1. Deterministic
2. No objective function
3. Based in a functional response of type II
4. Backward solution to link successive age-classes (MSVPA) using newton-raphson method
5. "terminal F" tuned to single-species age-structured models
6. Point estimates of suitability coefficients and predation mortalities

MSVPA equations

$$N_{a+1,t+1} = N_{a,t} e^{-(F+M1+M2)} \qquad C_{a,t} = F_{a,t} \bar{N}_{a,t}$$

$$M2_{p,b} = \sum_i \sum_a \frac{S_{i,a,p,b} R_{i,a} \bar{N}_{i,a}}{BS_{i,a}} \qquad BS_{i,a} = S_{of} B_{of} + \sum_p \sum_b S_{i,a,p,b} W_{p,b} \bar{N}_{p,b}$$

BS - suitable prey biomass

S - suitability coefficient of prey *p* for predator *i*

R - annual ration of the predator *i*

W - weight at age of prey *p*

M1- residual mortality

M2 - predation mortality

MSVPA equations

$$S_{p,a,i,j} = \frac{U_{p,a,i,j} / (\bar{N}_{p,a} W_{p,a})}{\sum_p \sum_a U_{p,a,i,j} / (\bar{N}_{p,a} W_{p,a})}$$

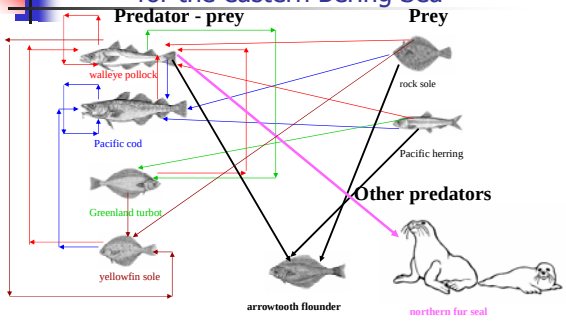
S - suitability coefficient of prey *p* for predator *i*

$U_{p,a,i,j}$ represents the predator stomach content,

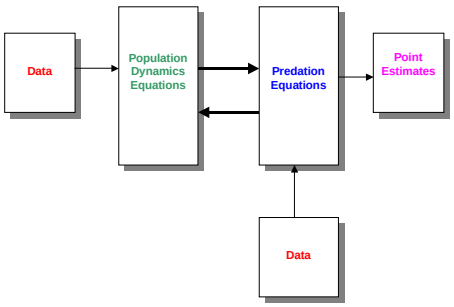
$W_{p,a}$ the weight of the prey in the stomach of the predator

$N_{p,a}$ the average stock size of the prey

Biomass flow in the system defined for the eastern Bering Sea



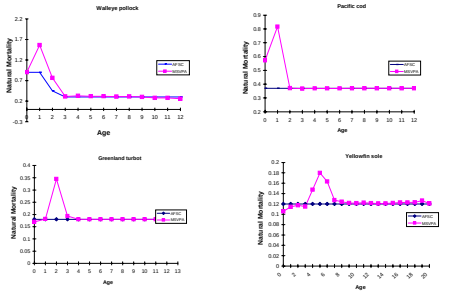
Multispecies VPA



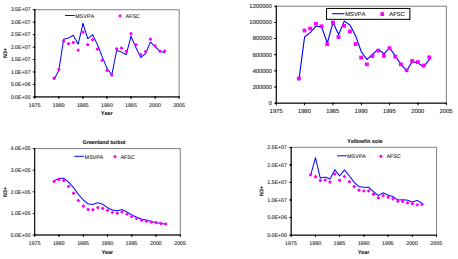
Stomach contents data

Year	Quarter I	Quarter II	Quarter III	Quarter IV
1981		COD		
1982	NFS	NFS,PLK	NFS	NFS
1984			ATF,COD,GTB, YFS	
1985	ATF,COD,GTB, NFS,PLK,YFS	COD,GTB,NFS, PLK,YFS	ATF,COD,GTB, NFS,PLK,YFS	ATF,COD,GTB, NFS,PLK,YFS
1986		ATF	ATF,COD,GTB, PLK,YFS	ATF,PLK
1987	PLK,YFS	COD,PLK	ATF,COD,GTB, PLK,YFS	COD,PLK
1988			ATF,COD,GTB, PLK,YFS	PLK
1989	COD		ATF,COD,GTB, PLK,YFS	PLK,YFS
1990		ATF,PLK		
1991		COD		
1992				
1993	PLK			

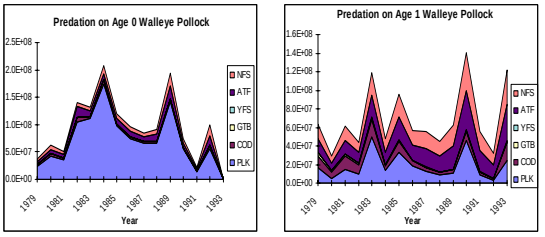
MSVPA: predation mortality estimates



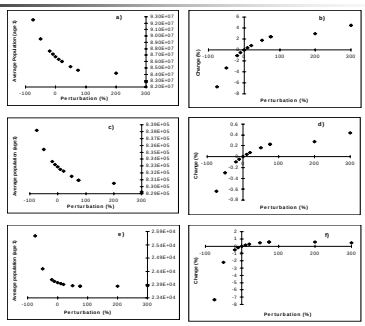
MSVPA: stock size estimates



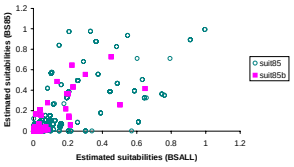
Predation on walleye pollock



Sensitivity analysis (other food parameter)



Stability of the suitability coefficients



Slope 0.95 ± 0.02 intercept = 0.01 ± 0.002. (H0: β = 1, p-value = 0.01).

walleye pollock as prey (Ho: β = 1; walleye pollock, p-value = 0.64; yelowfin sole, p-value = 0.21; northern fur seal, p-value = 0.94)

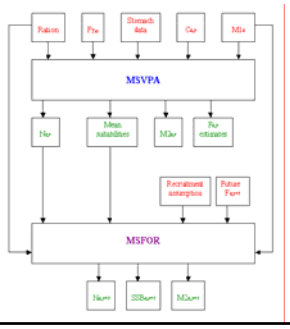
MSFOR

- MSFOR is the predictive counterpart of the MSVPA and uses the predation equations, the average suitabilities, future F's , ration and recruitment assumption to simulate the future dynamics of the species and the indirect effect of fishing on no target species in the long-term

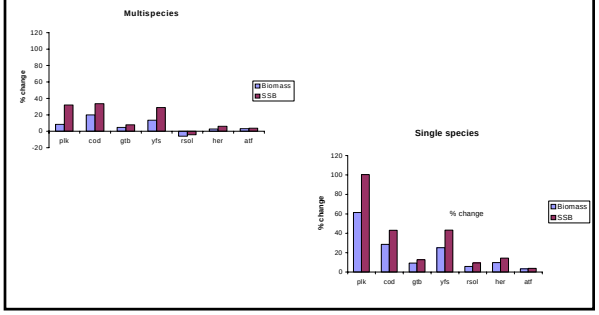
MSFOR characteristics

- Deterministic
- Able to measure indirect effects of fishing in different management scenarios
- Constant average suitability coefficients from MSVPA

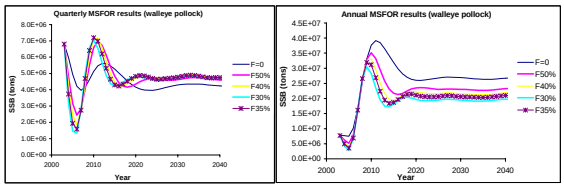
MSVPA-MSFOR models



Long-term percentage change (F_{ref} vs F=0)



Results MSFOR: SSB in the long-term



Multispecies statistical model

- MSM uses a forward algorithm and uses catch-at-age data, **indices of relative abundance**, predator ration and predator diet information to estimate F, recruitment, stock size, **suitability coefficients** and **predation mortality** in a statistical framework.

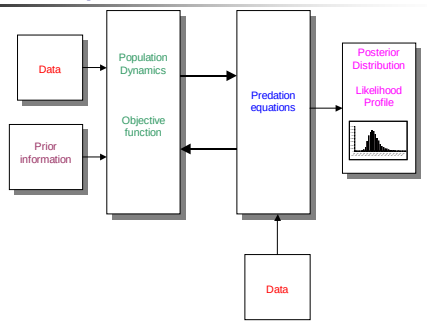
MSM characteristics

1. Process and observation error.
2. Objective function (likelihood)
3. Based in a functional response of type II
4. Forward solution
5. Estimates initial age-structure, recruitment, F_{full} and selectivity
6. Posterior distribution for suitability coefficients and predation mortality

MSM: assumptions

- Separable fishing mortality assumption ($F_{a,t} = s_a F_{full,t}$)
- M= M1+ M2
- Constant predator ration
- Constant suitability coefficients
- Stomach content measured without error
- Recruitment of age-0 individuals takes place in the third quarter

Multispecies statistical model



Advantages of MSM:

- Multispecies approach
- Measuring indirect effects of fishing
- We can use the tools used in single species stock assessments
  - Likelihood profile
  - Bayesian analysis (posterior distributions)
  - Decision analysis
  - Model selection (Akaike's information criterion,likelihood ratio)
  - Able to make comparisons with the single-species stock assessment models in the same statistical framework

MSM: equations

$$N_{a+1,y+1} = N_{a,y} e^{-(M1_{a,y} + M2_{a,y} + F_{a,y})}$$

$$F_{a,y} = F_{Full,y} S_a$$

$$s_a = \frac{1}{1 + e^{r - sa}}$$

MSM: equations

$$C_{a,y} = \left(\frac{F_{a,y}}{F_{a,y} + M1_{a,y} + M2_{a,y}} \right) N_{a,y} \left(1 - e^{-(F_{a,y} + M1_{a,y} + M2_{a,y})}\right)$$

$$L = -m \sum \ln(C_{Obs} / C_{pred})^2 / 2\sigma^2 - \sum \ln(I_{pred} / qB_{pred})^2 / 2\sigma^2$$

$$\hat{q} = \exp\left(\frac{1}{n} \sum \ln\left(\frac{I_t}{\hat{B}_t} \right) \right)$$

MSM: predation equations

$$M = M1 + M2$$

$$M2_{p,b} = \sum_i \sum_a \frac{S_{i,a,p,b} R_{i,a} \bar{N}_{i,a}}{BS_{i,a}}$$

$$BS_{i,a} = \sum_p \sum_b S_{i,a,p,b} W_{p,b} \bar{N}_{p,b}$$

$$S_{p,a,i,j} = \frac{U_{p,a,i,j} / (\bar{N}_{p,a} W_{p,a})}{\sum_p \sum_a U_{p,a,i,j} / (\bar{N}_{p,a} W_{p,a})}$$

S - suitability coefficient of prey *p* for predator *i*

BS - suitable prey biomass

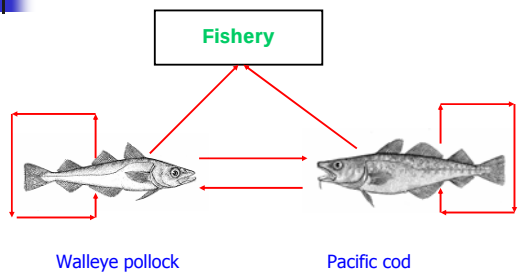
R - annual ration of the predator *i*

W - weight at age of prey *p*

M2 - predation mortality

U - stomach content

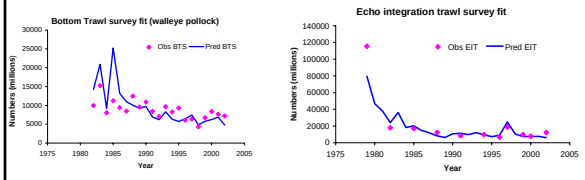
Methods: reduction of the number of species in the system



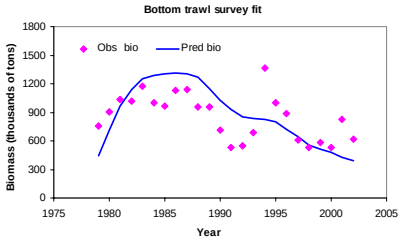
Methods

- Initial run of the MSVPA updated to 2002.
- Run of Multispecies statistical model updated to 2002.

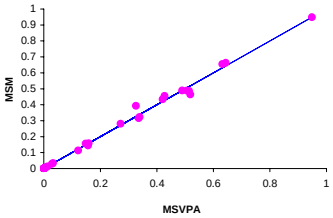
MSM results: walleye pollock model fit



MSM results: Pacific cod model fit

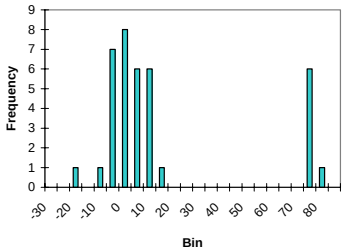


MSM results: comparison of MSM-MSVPA suitability coefficients



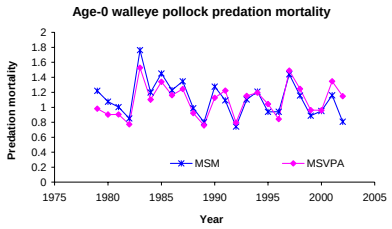
r^2 = 0.9951 Slope = 0.99 Intercept = 0.0007

MSM results: Percentage deviations between MSVPA-MSM suitability coefficients

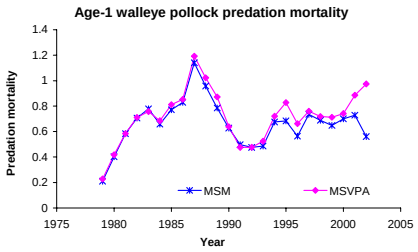


.0001 -> .00018

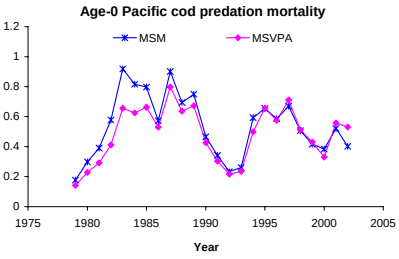
MSM Results: comparison of MSVPA-MSM predation mortality estimates



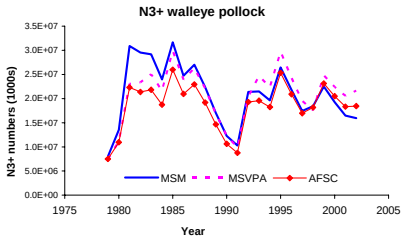
MSM results: comparison of MSVPA-MSM predation mortality estimates



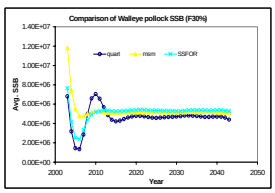
Results: comparison of MSVPA-MSM predation mortality estimates

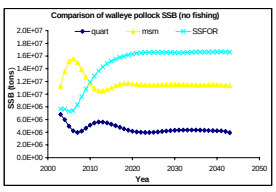


MSM results: comparison of N3+ walleye pollock estimates

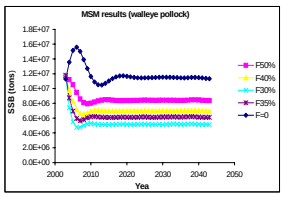


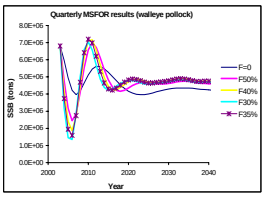
Forecasting results:





Forecasting results:





Multispecies models: limitations

- MSVPA and MSFOR:
1. Constant suitability coefficients
2. Stability of the suitability coefficients
3. Constant predator ration
4. No prey switching
- MSM
1. Constant predator ration
2. No prey switching

Future tasks

- MSVPA
1. Addition of new stomach data for MSVPA
- MSFOR
1. Incorporation of Ricker's and Beverton and Holt stock-recruitment curves.
- MSM
1. Addition of the complete set of stomach content data
2. Incorporation of the rest of the species to MSM
3. Incorporation of Ricker's and Beverton and Holt stock-recruitment curves.
- Linking AFSC single-species stock assessments models with predation equations
- Implementing technological interactions in MSM and MSFOR